The impact of vowel duration on locus equation slopes.

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Abstract

The aim of this paper is to examine the role of vowel duration contrast on locus equation slopes. Three Jordanian speakers produced long and short vowels with five consonants in CVC words. These words were analysed using Praat to obtain the acoustic data which was used to calculate locus equations for both long and short vowels. Results show that there is a significant difference between locus equation slopes of long v.s short vowels.

Keywords: Acoustic analysis, Locus equation, Vowel duration, Jordanian Arabic.

1 Introduction

Formant transitions are among the most described patterns in speech production.

- They represent frequency changes that happen because of the movements of the articulators in the vocal tract ;
- They are therefore associated with the articulatory transitions from a consonant to a vowel or from a vowel to a consonant.

Classical studies [1] held that the directions of these transitions provide information about the place of articulation of stop consonants.

But Öhman [10] argued that the concept of the fixed *locus* is not consistant with the dynamic nature of speech production. The concept of *locus equation* was originally proposed by Lindblöm [5] and has later been developed by Sussman [8] to solve this issue.

- Locus equations represent the linear relationship between the initial and the mid point of the second formant;
- According to Sussman [6, 7], locus equations constitute a source of relational invariance for the identification of stops' place of articulation.

In this study we are interested in the role of vowel duration on locus equation slopes. Vowel duration is considered as an important cue in speech perception [9]. It may be associated with vowel length phonological contrasts as well as to variations in speaking rate and vowel accentuation depending on languages. It is usually associated with vowel length phonological contrasts in certain languages (long vs. short vowels). Variations in vowel duration may also be associated with variations in speaking rate [2]: fast speaking rates tend to reduce vowel durations, while slow speaking rates increase vowel durations. But temporal effects may also be related to spectral properties. As a matter of fact, changes in formant frequencies may occur in relation to vowel length [3].

2 Hypothesis

Several studies [2, 4] have found that there is only a weak impact of vowel duration on the spectral properties of vowels and that the variations of duration in different speaking rates do not influence the frequency of vocalic formants. However, Hadding-Koch and Abramson [3] have argued that vowel duration contrasts may influence formant frequencies in Swedish vowels.

- When locus equations are computed, the temporal dimension is abstracted away: the computation of locus equations does not involve any temporal dimension, although it is derived from a representation that contains time;
- We argue that in the case of vowel duration contrasts, variations of duration may influence patterns of formant frequency which may in turn produce deterministic modifications of locus equations.

The aim of this research is to investigate the role of vowel duration opposition on the properties of locus equations.

3 Method

- Three male native speakers of Jordanian Arabic participated in a speech production experiment in order to investigate this hypothesis.
- C1VC and CVC1 words were selected from the Arabic lexicon (with C1 = /t,t',k,q,ʔ/ and V = /a,u,i,aː,uː,iː,oː,eː/). Among all, each of these conditions (8 vowels, 5 consonants, 2 syllabic positions) was combined to select 80 actual arabic words that were read by the speakers.
- Relevant C1 consonants appeared in both initial and final position within a fixed carrier sentence (/ħaka ... marteːn/ : he said ... twice). Each of these 80 sequences was repeated 15 times in a random order. Speakers were asked to read carrier phrases along with the target CVC patterns which were appearing on a PC screen. There were 1200 recordings for each speaker.

Formant frequency tracks along with their corresponding temporal positions were extracted using the *Praat* software. An R script transformed the raw acoustic data in order to locate F2-onset and F2-mid for each of the 15 repetitions of a consonant in a particular context. Linear regressions of these data points were then produced in order to estimate the parameters of each of the 60 locus equations (5 consonants $\times$ 2 vowel lengths $\times$ 2 syllabic positions $\times$ 3 speakers), an example of such a linear regression is displayed in Figure 1.

To avoid the influence of extreme values on locus equation slopes, outliers were automatically indentified based on sample residuals from the first linear regression. Then a second linear modelling was performed without the outliers. These outliers represent only 9.6% of the total data.

4 Results

As mentioned previously, the aim of this research was to study the role of vowel duration contrast on locus equation slopes. We found that the slopes of a consonant associated with long vowels are lower than the slopes of the same consonant associated with short vowels, see Figure 2 and Table 1. We can notice that the values of R^2 are all ≥ 0.85.

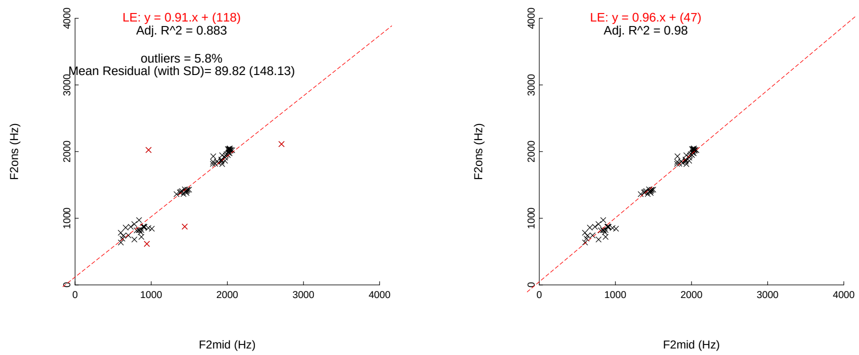

Figure 1: Two representations of a locus equation slope of the consonant /?/ produced by speaker: L1 with long vowels in final position, with and without the outliers respectively.

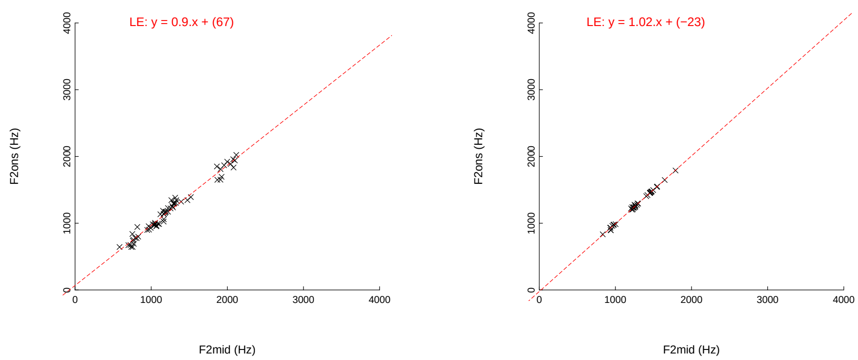

Figure 2: Two locus equation slopes of long (left) vs. short (right) vowels respectively, produced with the consonant /q/ in final position by speaker: L3.

A three-way ANOVA was conducted to compare the effects of vowel duration on locus equation slopes. Results indicates that there is no interaction between the different variables. The slopes of long vowels differ significantly from those of short vowels across all consonants, $F_{(1,2)} = 43.81, p < 0.05$. In addition, there is a main effect of consonant category on locus equation slopes, $F_{(4,8)} = 12.46, p < 0.01$. Another three-way ANOVA was conducted to compare the effects of vowel duration on locus equation *intercepts*. None of the interaction effects reaches significance. Results show that there is only a marginal difference between long vs. short vowel intercepts across all consonants, $F_{(1,2)} = 16.43, p = 0.0558$.

	Slope		Intercept		R^2	
Consonant	Short V.	Long V.	Short V.	Long V.	Short V.	Long V.
t	0.85	0.74	260.86	461.84	0.97	0.97
t'	0.90	0.70	103.10	329.96	0.99	0.85
k	1.06	1.03	-59.39	-26.821	0.97	0.93
q	0.89	0.87	117.73	135.15	0.94	0.92
?	1.04	0.97	-77.86	35.31	0.98	0.97

Table 1: Mean values of locus equation slopes, intercepts and R^2 computed for each consonant coarticulated with respectively short and long vowels.

Results also show a significant difference between consonants intercepts across all vowels, $F_{(4,8)} = 11.04, p < 0.01$.

5 Discussion

According to Sussman and his collaborators, locus equation slopes are a good indicator of stop place of articulation. Indeed, our statistical analyses indicate that slopes and intercepts of the investigated consonants are significantly different across all vowels. However, further work needs to address how these 5 individual consonant categories behave with respect to these parameters.

Though the present Locus Equation data are overall in line with this model, it appears that they are systematically influenced by alternations in vowel length. This influence manifests itself mainly on Locus Equation slopes, as the effect on intercepts is only marginal. According to our predictions, locus equations are therefore influenced by parameters that are associated with time whereas they represent linear relationships between spectral information. This may put strong constraints on the interpretation of locus equations for the identification of place of articulation in speech perception mechanisms.

However, we also observed that variations of vowel length are strongly associated with modifications of spectral configuration measured at the vowel midpoint: long vowels exhibit higher F2 frequencies than short vowels in our sample. The impact of vowel length on locus equation slopes may therefore be a consequence of this vowel modification. Further work is planed on French language to investigate the role of vowel duration variations (based on speaking rate differences) on locus equation slopes as variations in vowel duration may vary indepently of spectral content.

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